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# A HIGH-PRESSURE LIGHT-GAS GUN



Leon Horn

26 July 1961



DIAMOND ORDNANCE FUZE LABORATORIES
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FOR THE COMMANDER:
APPROVED BY

Israel Rotkin

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Chief, Laboratory 300

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**ABSTRACT**

A new single-stage, high-pressure, stainless-steel, light-gas gun 30 ft long with a 1 3/8-in bore has been designed and built at DOFL. This gun has driven a 6-gm mass at velocities above 5000 fps. With alterations made to heat the driver section, it is expected to give velocities of over 8000 fps and make possible impact shock pressures of more than 1-megabar.

A comparison of the measured and computed projectile velocities at room temperature as well as higher temperatures is included.


## 1. INTRODUCTION

Solids can be compressed statically or dynamically. In general, the choice is determined by the pressure desired, since pressures of over 400,000 atm require dynamic methods. In addition, there are theoretical differences in the nature of the pressures generated so that for special cases it can be desirable to produce low pressures dynamically.

At DOFL a 4-in-bore light-gas gun capable of 4200-fps projectile velocities has been available for studies of the shock compression of solids (ref 1). The decision was made in 1960 to increase the range of shock compressions by building a small higher-velocity light-gas gun.

The light-gas gun built is essentially a long tube containing a scored diaphragm that divides a high-compression section called the driver section from a low-pressure section, which is evacuated and contains the projectile. The rupture of the diaphragm releases the compressed gas, helium, and the projectile is accelerated down the evacuated gun by the expanding gases, until it hits the target. Figure 1 is a block diagram of the light-gas gun system.

Dry helium gas has an advantage over explosives, since a blast of dry gas is sufficient to clean out particles left in the gun after a shot and the inert character of dry helium results in a low erosion rate of the gun.

When a rapidly moving solid collides with another solid, a shock wave is generated. Depending on the solids, shock compressions with pressures from 15,000 to 700,000 atm are easily attained with the light-gas gun. The pressure developed during the collision between like bodies can then be determined if the velocity of the moving unit, shock-wave velocity in the material, and the change in volume that results, are known. The Rankine-Hugoniot relationship between pressure and density through a normal shock wave is generally used for the final pressure determination. A detailed account of such calculations can be found in reference 2.

The shock pressure generated is a function of the material impacted and its velocity. The final velocity of the projectile in the light-gas gun is determined by the driving-pressure/projectile-weight ratio at which the diaphragm ruptures. Since this ratio as well as the choice of material chosen is directly controlled by the experimenter, the pressure generated during any single test can be selected in advance. Thus, by the proper choice of the variables, the final velocity of the projectile and the resultant compression can be controlled. The pressure in the impacted material can be varied continuously from very small values to pressures comparable with those reached in metals by contact explosives.

As a research tool, the light-gas gun allows one to bridge the pressures that have been reported by various authors using static presses and those using dynamic compression. As a result, it is possible to check against the published data at both ends of the pressure spectrum.

The projectile is continually guided down the gun until the impact takes place, and as a result the alignment of the projectile to the target surface can be held to a fraction of a degree. One can expect erosion at the gun exit due to fragmentation of the target holder, target and projectile at impact. The gun exit contains a tempered-steel liner in a brass section that can be easily replaced if damaged. Figure 2 shows the steel liner, target holder, and clamping system for the target at the exit of the gas gun. The exit sleeve diameter is 1/2 in. larger than the bore of the gun and thus allows for essentially free flight the instant before impact. The muzzle of the gun extends through a heavy reinforced wall into a catch box room. To allow the impacts to be visible and to occur in a controlled atmosphere, when desired, an additional 18-in. section has been made that can be attached instead of the nozzle exit sleeve. This section (fig 3 and 4) has a 4 x 4 x 6-in. visible expansion chamber that can be evacuated or filled with a particular gas independently at a desired pressure.

The gun empties into a heavy metal catch box in the reinforced concrete room designed to withstand the sudden over-pressure of the driving gas and contain the fragments and shocks produced by an impact. The catch box room has an exhaust fan to remove the gaseous products of the impact, it also has viewing ports cut into its 8-in. walls to allow cameras to be set up outside the catch box room and still make records of the events occurring at the target.

## 2. MECHANICAL ARRANGEMENTS

The light-gas gun, components of which are shown in figures 5 and 6, is basically a 1 3/8-in. bore stainless-steel pipe, 28 ft long with a 1/4 in. wall. The gun is divided into two sections at the breech; one side, the

driver section, is 6 ft long. The high-pressure gas is contained in this section by a scored diaphragm of 52-SH-34 aluminum, held in a metal clamp and sealed with rubber O rings. Figures 7 and 8 show the diaphragm, the clamping section and the method of locking the high-pressure unit to the rest of the gun. The length of the high-pressure system was chosen to insure that reflections from the back wall of the pressurized tube would not reach the projectile before it emerged from the evacuated section.

In an attempt to achieve optimum flow characteristics after the diaphragm rupture, the breech section, at the entrance to the evacuated section, was contoured for 3/4 in. to allow space for the folded parts of the ruptured diaphragm. The exact shape and depth of the grooves inscribed on the diaphragm had to be selected and proved experimentally. Improper design would cause a throttling of the gas in this critical area.

The evacuated section of the gun contains two velocity-detecting ports, which contain sealed magnetic probes mounted flush with the inside walls. These ports are 13 in. apart with the last one 4 in. from the impact zone of the gun.

The fore section of the gun is evacuated by a rotary pump with a speed of 4.5 l/sec at 1 x $10^{-4}$ mm Hg. The inlet port to the vacuum system is directly behind and below the last velocity detector. From the exit port on the gun the vacuum tubing goes through a mechanical filter (its primary purpose is protection to the solenoids and vacuum pump from target and projectile fragments); then through a solenoid valve to a tee section. One tube of the tee goes through another solenoid valve through a manual ball valve to a Stokes-McLeod vacuum gage; the other goes through a cold trap past a tap for the continously measuring Pirani vacuum gage, then to the vacuum pump.

The total volume to be evacuated is 15 l as a result, the pumping time is limited only by the type of vapors in the system. In practice, it is found that pressures of less than 3μ Hg can be achieved in approximately 15 min from a cold start, and this pressure can easily be maintained for the necessary 3 to 4 min after the vacuum system is isolated from the pump. This allows sufficient time to pressurize the high-pressure chamber and rupture the diaphragm without losing the desired vacuum in the muzzle end of the gun.

## 3. DIAPHRAGMS

Previous tests at various installations confirmed at DOFL have indicated that machined scored surfaces could be designed to rupture evenly and quickly with little interference to the flow. By taking advantage of the practical experience gained in designing a quick-opening diaphragm at DOFL, it was possible to make scored 0.063-in. 52 SH 34 aluminum disks that would perform as required. These disks were found to be satisfactory at pressures from 1300 psi to 2000 psi.

The inertia of the sections of the diaphragm (i.e. the thickness of the diaphragm and the geometry of the cuts), as well as the rigidity of the material chosen, determine the time for a good design to open completely (from 10 to 120 μsec).

At lower pressures the petals did not fold back completely and the final velocity of the projectile was reduced. The scored design chosen was in the form of a cross with incomplete arcs across the end of each arm. Figure 9 shows the scored diaphragm before and after use. No fragmentation was ever observed during tests using this configuration.

## 4. OPERATION

The target assembly is installed in the muzzle sleeve with the O ring seal in place. Figure 10 shows the target-retaining system. The catch box room is closed and the warning sign is placed over the door. The diaphragm and projectile are loaded at the breech and the gun is sealed. The vacuum pump is now turned on. When the desired vacuum is reached, the solenoid that cuts off the pump from the gun is actuated and the alarm buzzer is pressed. Immediately afterwards, high-pressure helium is admitted to the breech side of the diaphragm. The moment of firing is governed by the rupture of the diaphragm, which allows the highly compressed gas to flow, driving the projectile before it. The sound of the rupture is the signal to allow the open valve from the compressed gas storage tank to close. The impact of the projectile on the target takes place a few milliseconds after the rupture of the diaphragm.

The dimensions of the gun bore are regular enough to allow the projectile to be machined to close tolerances. For the light-gas gun, the projectile is a hollow metal cylinder whose weight varies from a low of 6 gr to a high of 50 gr, depending on the requirements of the experiment. The back edge of the projectile is punched 0.010 in. deep at three places to form three little prongs 120° apart which prevent the unit from sliding freely beyond the relieved area of the breech (fig 9). The sudden gas pressure shears these prongs off and drives the projectile down the gun. A 1-in. projectile has sufficient clearance between it and the gun bore to make possible a tilt of 10 min of arc in its alignment in the gun. Actually, due to wall effects, one would expect an even smaller degree of tilt of the projectile's major axis during flight. As a result, the impact angle can be predetermined within 10 min by the initial position of the target plate.

## 5. VELOCITY MEASUREMENT

The velocity of the projectile is determined as it passes two magnetic inductive probes 1 ft apart. The velocity thus determined is slightly less than the possible velocity at impact, since the projectile is still accelerating after it passes the last probe. Each probe is basically a coil of wire wound about a small permanent magnet; changes in the magnetic field flux induce a voltage in the coil. These pickups have the advantage of simplicity of operation, requiring no amplifiers

to trigger counters. In practice, since the voltage output is related to the rate of change of flux at projectile velocities of more than 2000 fps, the probes give an output pulse of more than 150 v. The output pulses from the probes are used to trigger a Berkley 770 Time Interval Counter and also are continuously displayed on a 555 dual-beam Tektronix scope. Photographs are taken of the sweep signal on the scope face. In this way we can determine the velocity of the projectile by the counter, as well as monitor the output of each pickup during the entire flight. The shape of the output pulse can be related to the shape and condition of the projectile. Knowing the scope sweep rate, the velocity of the projectile can be checked independently by measuring the time between the probe pulses as recorded on film.

## 6. RESULTS

The theory used in designing the section lengths of the single-stage light-gas gun can be found in the appendix of reference 3. The operation of the gun was checked by comparing the predicted projectile velocities with the measured velocities. Figure 11 shows both the theoretical values calculated and the experimental velocities measured during the tests of this design. As can be seen, the results at room temperatures indicate reasonably close agreement up to 5200 fps.

With the addition of a supply 3500-psi helium gas, it should be possible in the near future to drive 12-gr projectiles at velocities of over 5000 fps.

Thus far, all tests have been made using hollow aluminum projectiles. Plastic projectiles with metal inserts could be designed to weigh about 3 gr, and (in theory) if they remain in one piece, will increase the peak velocity to 5500 fps.

Calculations based on a perfect gas indicate that heating the driver gas should give a large increase in the possible maximum velocity. Figure 10 shows the velocities possible for various pressure-mass ratios at four temperatures: normal room temperature 21°C to 27°C or 300°K and simple multiples of this absolute temperature, 600°K-327°C, 900°K-627°C and 1200°K-927°C.

## 7. REFERENCES


1. The 4-in. Light-Gas Gun, H. R. Kollmeyer, DOFL TR-933 (Aug 61)

2. Solid State Physics Vol 6, 1958, Academic Press - pp 1 - 63

3. Strong Shock Waves in Polled Barium Titanate Elements, P. S. Brody, DOFL TR-869 (20 Oct 60)

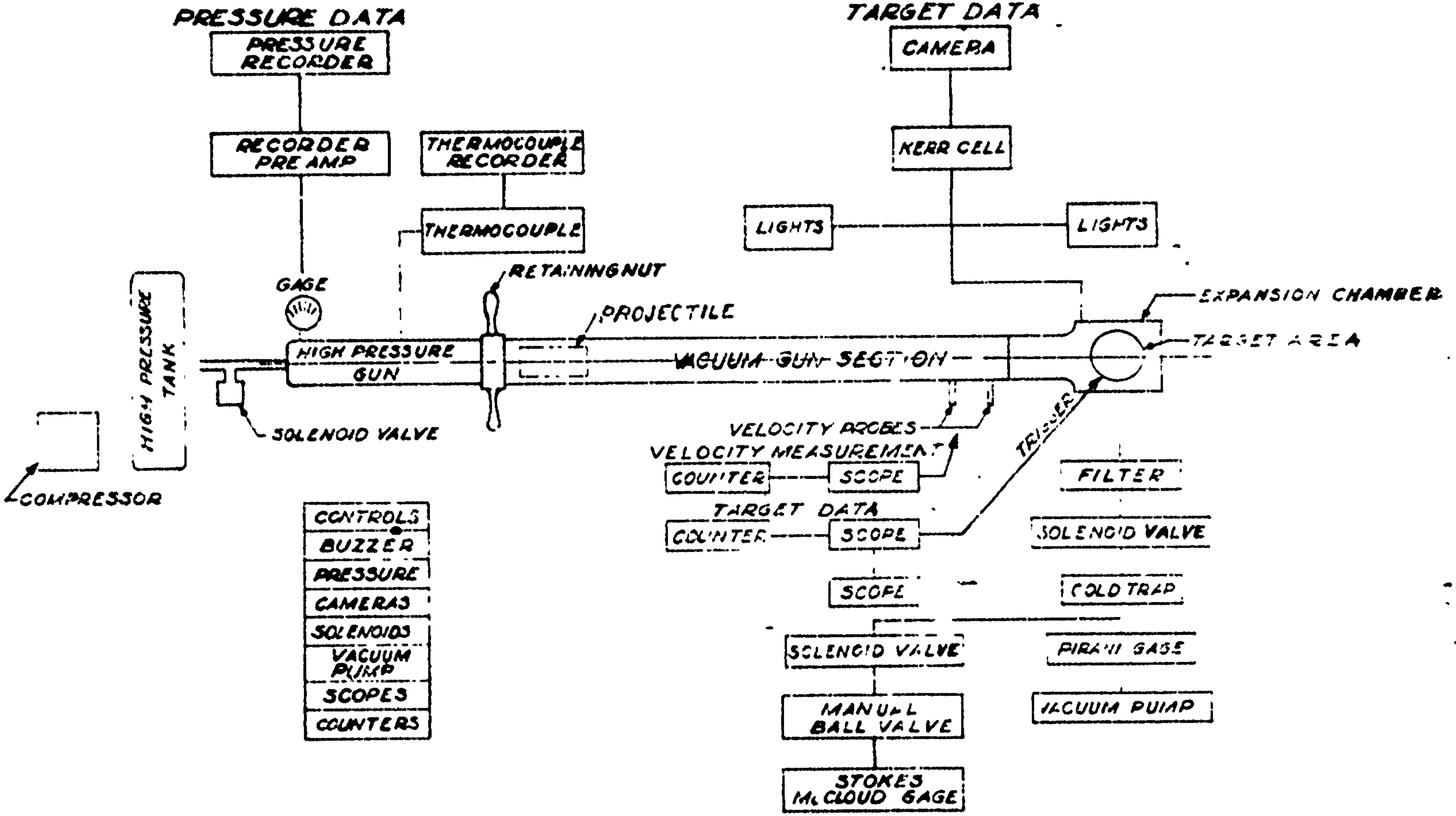


**Figure 1. Light-gas gun system**

Figure 2. Target Section

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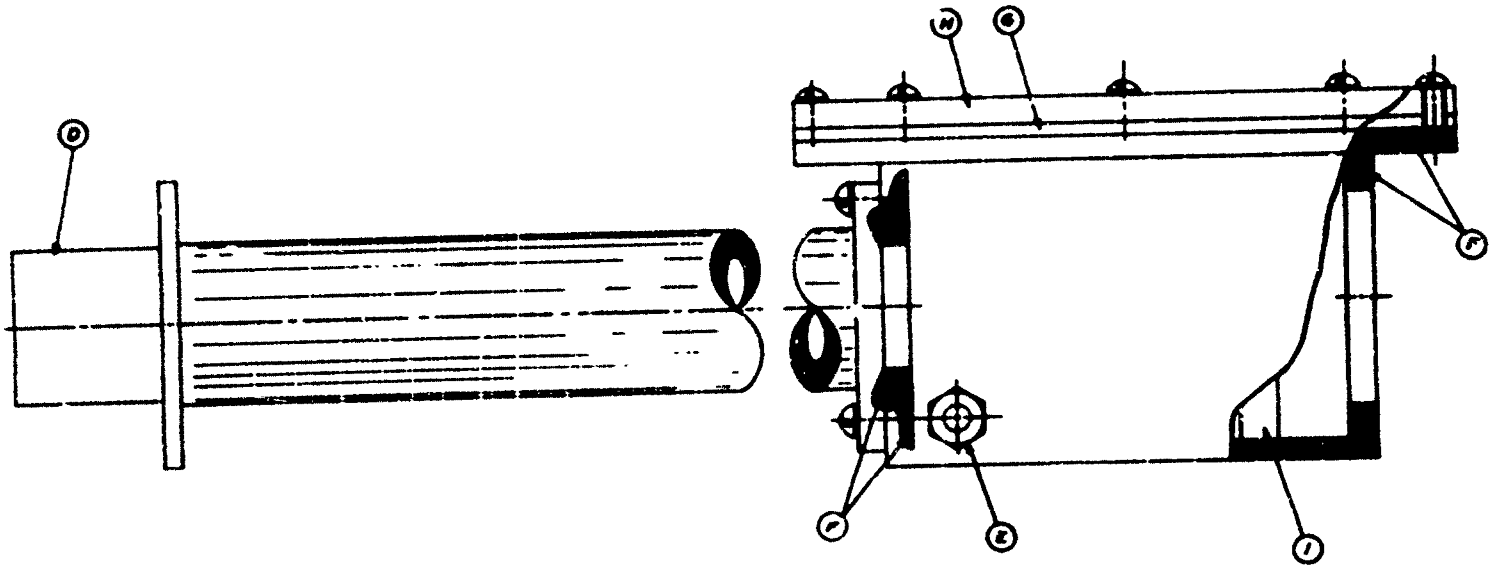


Figure 3. Target-viewing chamber.

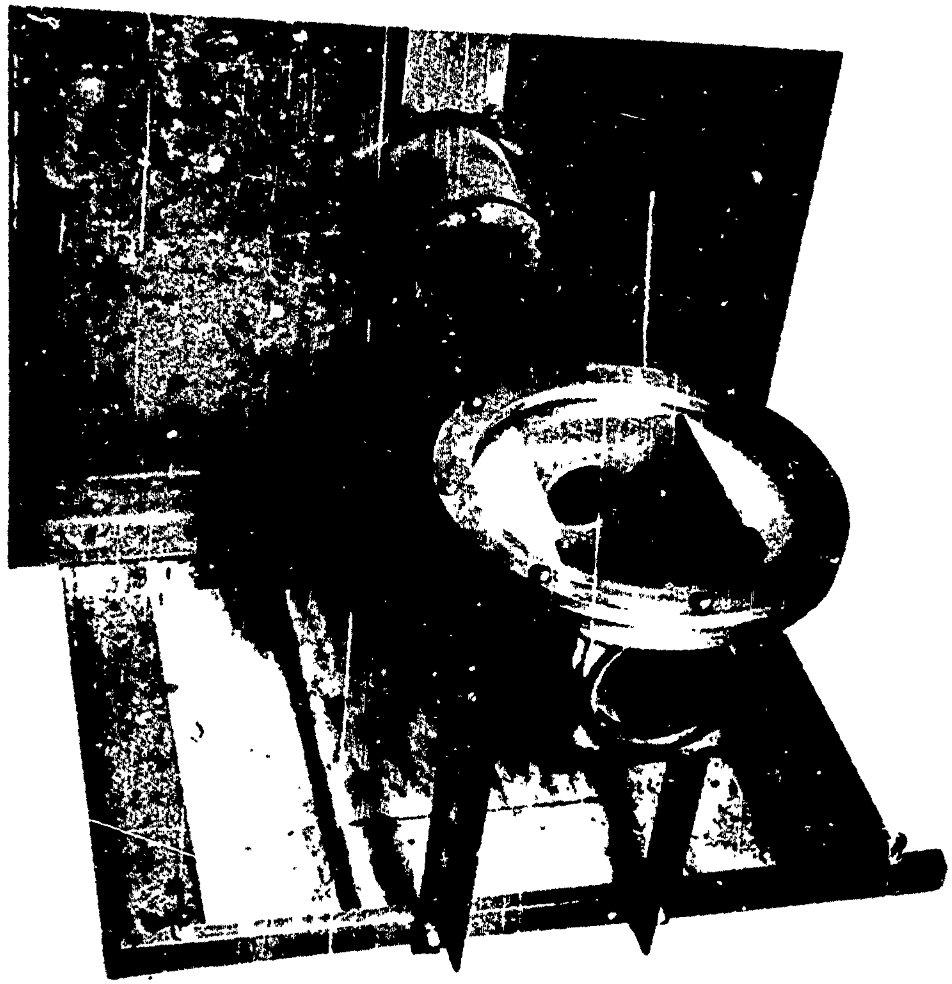

Figure 4. Target-viewing chamber

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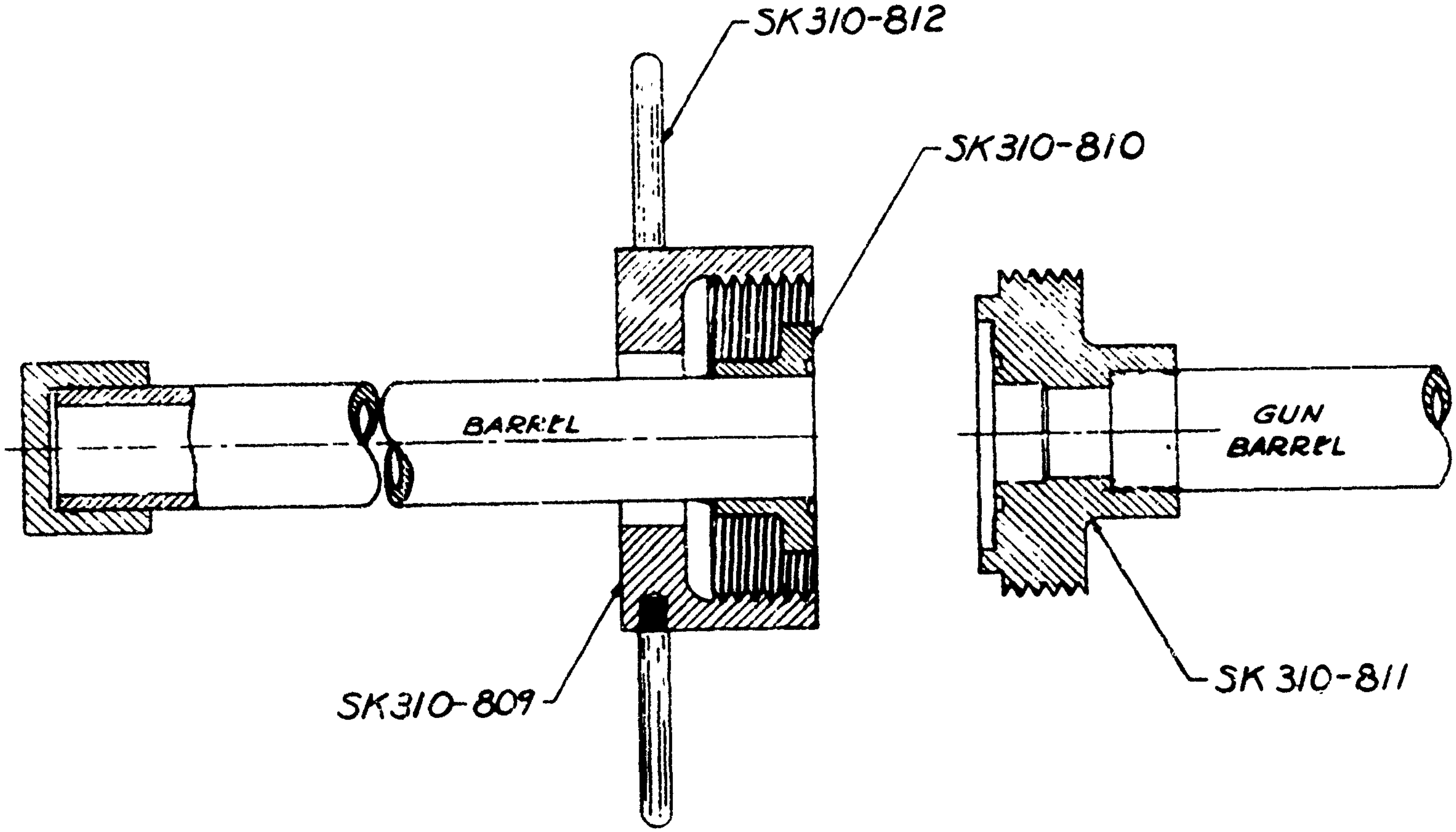


Figure 5. Diaphragm-retaining nut and clamping system.

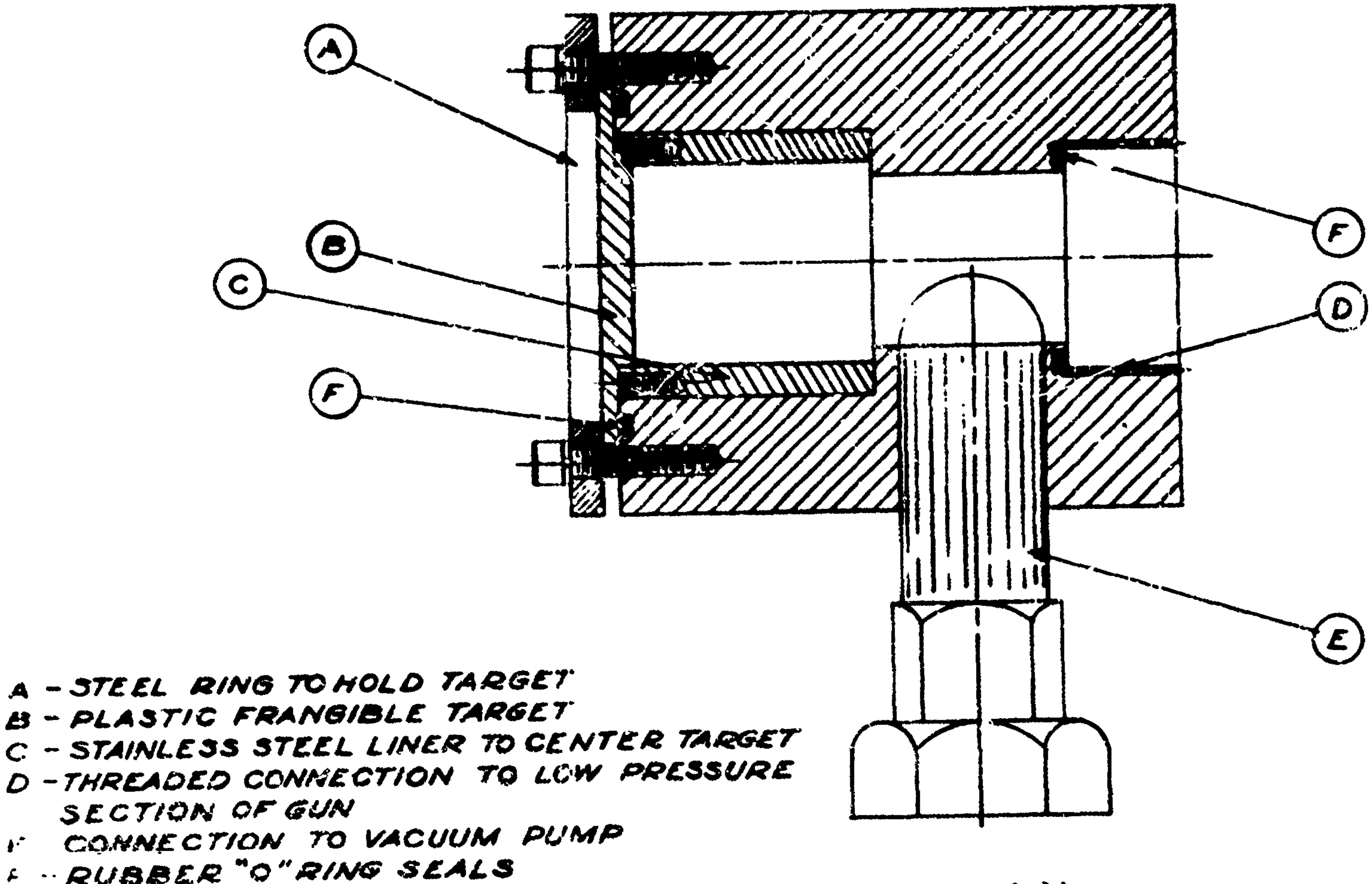


Figure 6. Target holder.

Figure 7. Diaphragm-retaining system, open 3364-60

Figure 8. Diaphragm-retaining system, closed

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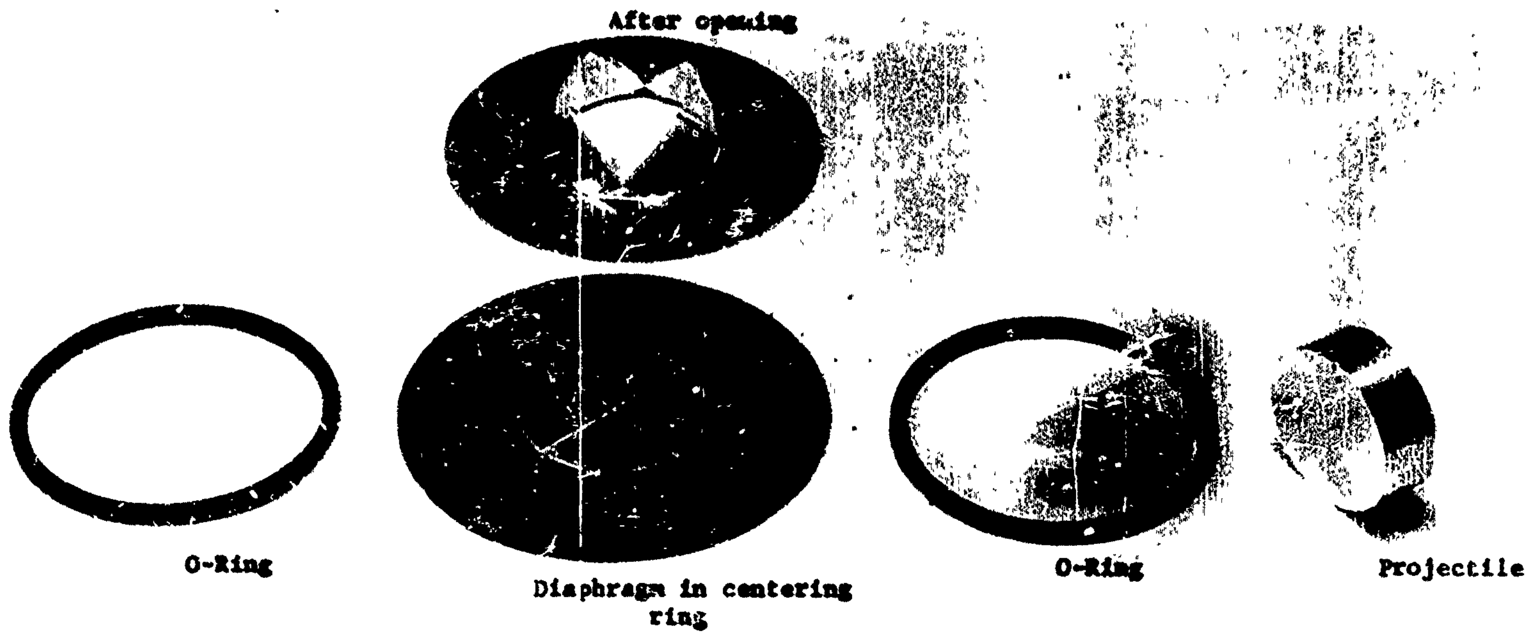


Figure 9. Diaphragm and O-Rings

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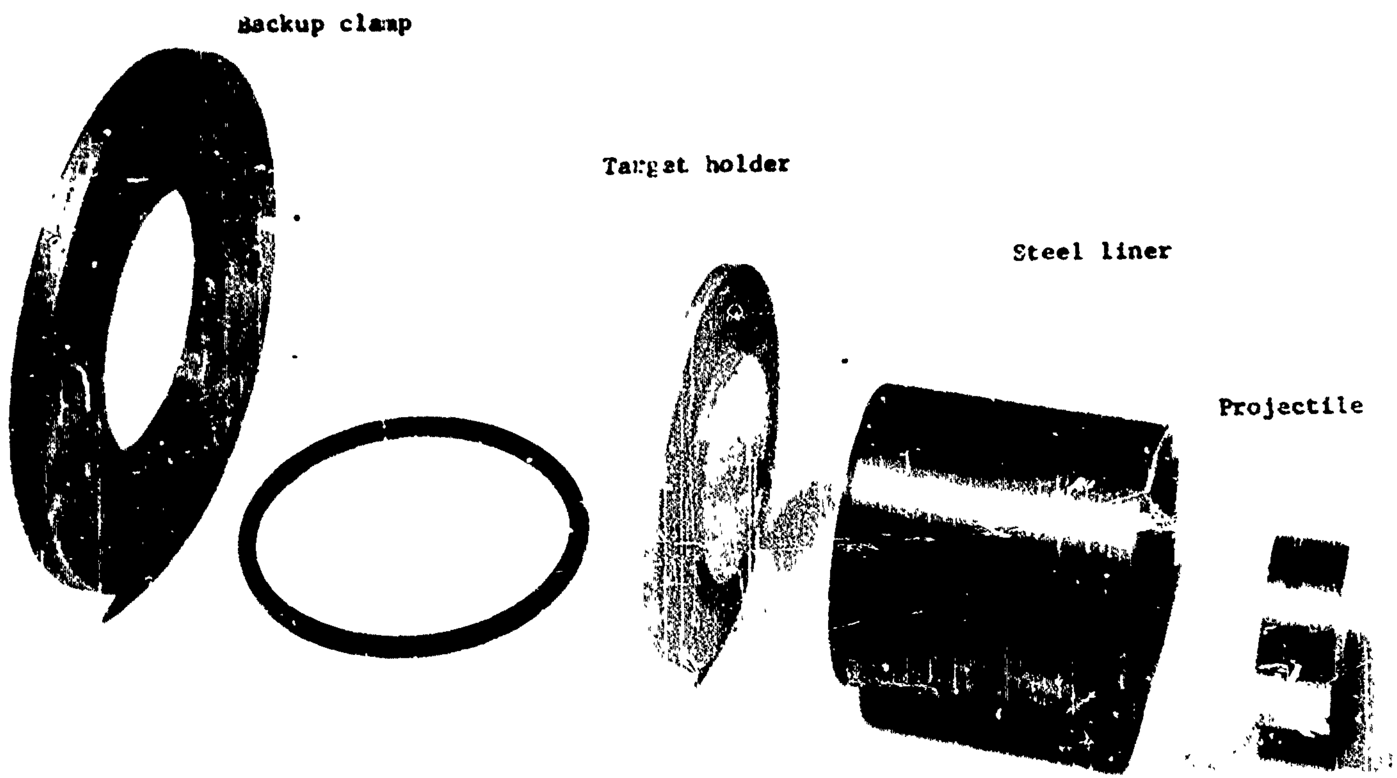


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Figure 10. Target-Retaining System

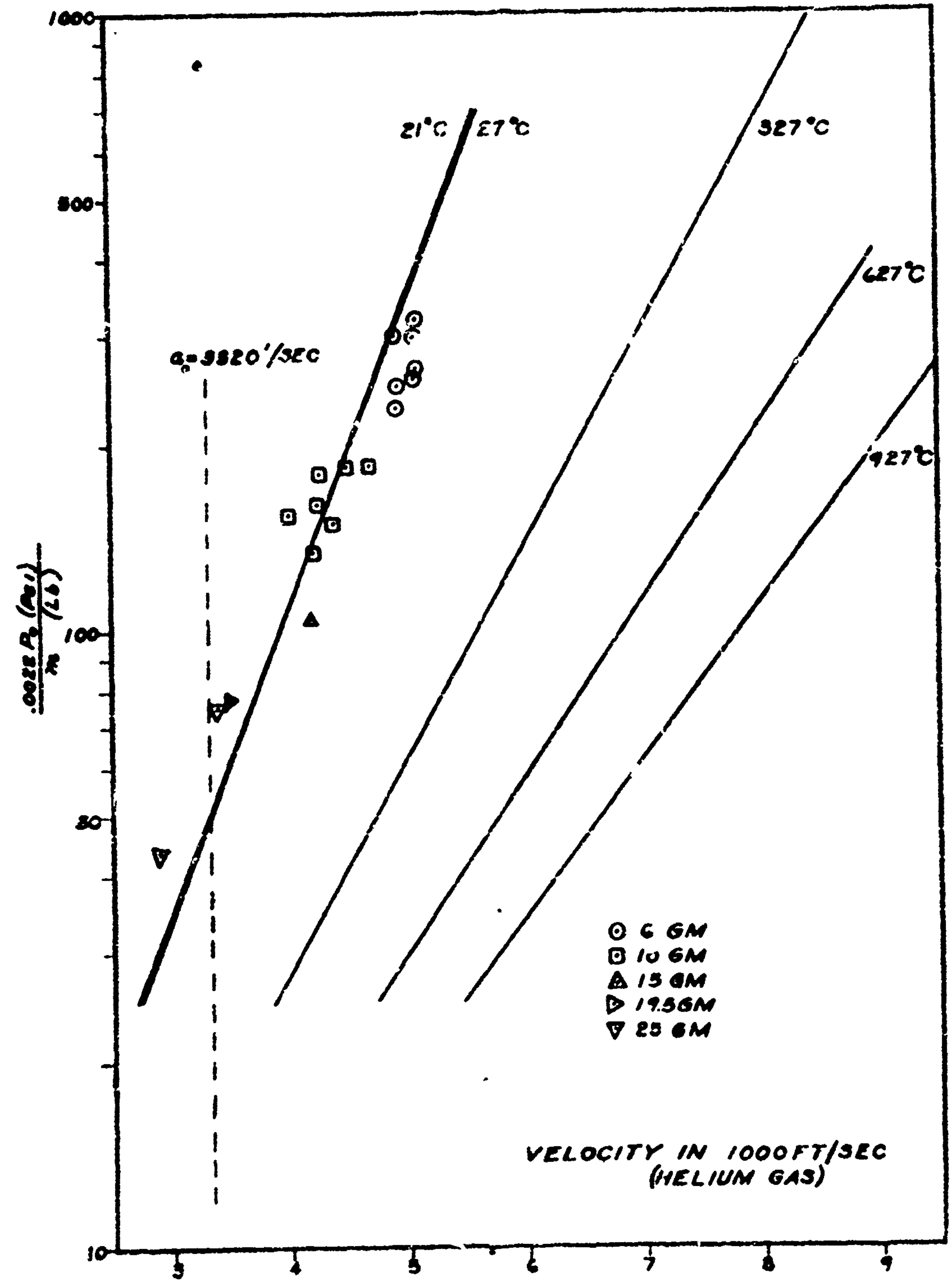


Figure 11. Measured versus computed projectile velocities (helium gas).

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1. Hypervelocity guns—Study
2. Shock tube

A new single-stage, high-pressure, stainless-steel, light-gas gun 30 ft long with a 1 3/8-in. bore has been designed and built at DOFL. This gun has driven a 6-g mass at velocities above 5000 fps. With alterations made to heat the driver section, it is expected to give velocities of over 8000 fps and make possible impact shock pressures of more than 1 megabar.

A comparison of the measured and computed projectile velocities at room temperature as well as higher temperatures is included.

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